

**COMPARISON OF FACTOR OF SAFETY USING DIFFERENT METHOD OF
ANALYSIS FOR SLOPE STABILITY**

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ABSTRACT

Slope failure in our country is an issue that needs to be taken seriously as it involves public safety. Therefore there are various efforts being carried out, particularly in the treatment of critical slope, redesign the slope that has failed and also analyze the factor of safety of the slope. This study was conducted to determine the safety factor of the slope at KM259.95 the North-South Expressway which is cut slope that built for infrastructure development, using computer software, Geo-studio 2007 (SLOPE / W) and the conventional method; infinite slope method in sand. Based on site investigation report, the slope has sandy soil profile. The first layer is silt with properties $\gamma = 18.25 \text{ kN/m}^3$, $c' = 0 \text{ kN/m}^2$, $\phi' = 39^\circ$, sand with properties $\gamma = 16.19 \text{ kN/m}^3$, $c' = 0 \text{ kN/m}^2$, $\phi' = 39^\circ$ and granite (impermeable). To carry out this analysis, three cross-sections have been developed to obtain the factor of safety. Using all the parameters, the factor of safety has been obtained for the three cross sections. Using conventional method, the factor of safety (FOS) for cross section A, cross section B and cross section C is 1.036, 1.000 and 1.036 respectively. While for the FOS for cross section A using SLOPE/W for Morgenstern Price, Janbu's, Ordinary and Bishop are 1.156, 1.091, 1.090 and 1.135 respectively. For the cross section B, the FOS for Morgenstern Price, Janbu's, Ordinary and Bishop are 1.509, 1.283, 1.303 and 1.392 respectively. And for cross section C, the FOS for Morgenstern Price, Janbu's, Ordinary and Bishop are 1.284, 1.250, 1.251 and 1.300 respectively. After obtaining the factor of safety for the slope, the coefficient for each type of analysis has been evaluated. For all cross section, the coefficient for Morgenstern Price analysis is 0.789, Janbu's method with 0.853, Ordinary method with 0.848 and Bishop Method with 0.809. The percentage difference between the factor of safety for SLOPE/W and conventional has also analyzed where Morgenstern Price method has the highest difference of 0.211% and the lowest percentage of different between both methods is Janbu's method with 0.147%. For the Ordinary and the Bishop method, the percentage difference is 0.152% and 0.191%. As a conclusion, factor of safety for cut slope of research is critical and requires immediate treatment with appropriate improvements. From percentage difference, both methods still suitable to be used as a way to get the optimum safety factor of slope.

ABSTRAK

Kegagalan cerun di negara kita merupakan satu isu yang perlu diberi perhatian serius kerana ia melibatkan keselamatan awam. Oleh itu terdapat pelbagai usaha sedang dijalankan, terutamanya dalam merawat cerun kritikal, merekabentuk semula cerun yang gagal dan juga menganalisis faktor keselamatan cerun. Kajian ini dijalankan untuk menentukan faktor keselamatan cerun di KM259.95 Lebuhraya Utara-Selatan yang merupakan cerun potong yang dibina untuk pembangunan infrastruktur, dengan menggunakan perisian komputer, Geo-Studio 2007 (SLOPE/W) dan kaedah konvensional; kaedah cerun tak terhingga dalam pasir. Berdasarkan laporan penyiasatan tapak, cerun mempunyai profil tanah berpasir. Lapisan pertama adalah kelodak dengan ciri $\gamma = 18.25 \text{ kN} / \text{m}^3$, $c' = 0 \text{ kN} / \text{m}$, $\phi' = 39^\circ$, pasir dengan ciri $\gamma = 16.19 \text{ kN} / \text{m}^3$, $c' = 0 \text{ kN} / \text{m}^2$, $\phi' = 39^\circ$ dan granit (tidak telap). Untuk menjalankan analisis ini, tiga keratan rentas telah dibangunkan untuk mendapatkan faktor keselamatan. Menggunakan semua parameter, faktor keselamatan telah diperolehi bagi tiga keratan rentas. Menggunakan kaedah conventional, faktor keselamatan (FOS) untuk keratan rentas A, keratan rentas B dan keratan rentas C adalah masing-masing 1.036, 1.000 dan 1.036. Manakala bagi FOS untuk keratan rentas A menggunakan SLOPE / W untuk Morgenstern Price, Janbu, Ordinary dan Bishop adalah 1,156, 1,091, 1,090 dan 1,135. Untuk keratan rentas B, FOS untuk Morgenstern Price, Janbu, Ordinary dan Bishop adalah 1,509, 1,283, 1,303 dan 1,392. Dan bagi keratan rentas C, FOS untuk Morgenstern Price, Janbu, Biasa dan Bishop adalah 1,284, 1,250, 1,251 dan 1,300 masing-masing. Selepas mendapatkan faktor keselamatan bagi cerun, pekali bagi setiap jenis analisis telah dianalisis. Untuk kesemua keratan rentas, pekali untuk analisis Morgenstern Price adalah 0.789, kaedah Janbu dengan 0.853, kaedah Ordinary dengan 0.848 dan Kaedah Bishop dengan 0.809. Perbezaan peratusan antara faktor keselamatan untuk SLOPE / W dan konvensional juga telah dianalisis di mana kaedah Morgenstern Price mempunyai perbezaan yang paling tinggi 0.211% dan peratusan terendah yang berbeza antara kedua-dua kaedah adalah kaedah Janbu dengan 0.147%. Bagi kaedah Ordinary dan kaedah Bishop, perbezaan peratusan adalah 0.152% dan 0.191%. Kesimpulannya, faktor keselamatan bagi cerun potong yang dikaji adalah kritikal dan memerlukan rawatan segera dengan penambahbaikan yang sesuai. Dari perbezaan peratusan, kedua-dua kaedah masih sesuai untuk digunakan sebagai satu cara untuk mendapatkan faktor keselamatan cerun yang optimum.

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LIST OF SYMBOLS

α = inclination of slip surface

β = inclination angle of slope

c' = effective cohesion of soil

E = Young Modulus

ϕ' = effective friction angle of the soil

L = length of slices

N = normal forces

S = shear strength

τ = Undrained shear strength

ν = Poisson ratio

W = weight of slice

γ = unit weight of soil

γ_{sat} = saturated unit weight

CHAPTER 1

INTRODUCTION

1.1 Background

Soil erosion is one phenomenon that has to be given attention in this country as has sparked a wide range of issues and problems in this country. Soil erosion occurs on cut slopes usually caused by natural factors and the consequences of human activities. Natural factors is difficult to predict and difficult to avoid regulations, but control measures and improvements should be done from time to time to prevent the occurrence of landslides. To solve the problem, slope stability analysis is performed to obtain a factor of safety of slope with conventional methods and software. As we know, the conventional method is still practicable to serve as a reference. For analysis using computer software, the factor of safety can still be idealized by multiplying by the coefficient to obtain the optimum value that can be derived from a comparison of the factor of safety between the conventional method and computer software, Geo-Studio 2007 (SLOPE/W).

1.2 Problem statement

Since the recent 20 years, more frequent landslides occur mainly slope in the path of the highway, a residential and industrial area which has resulted in deaths and huge property losses. Results of the investigations carried out by the authorities, main factors landslides is rainfall in Malaysia uncertainty and indirectly increase the rate of surface runoff in a critical slope. In addition, slope failures also occur when there is increased pressure and shear strength of the soil decreases. To reduce the risk of landslides, various attempts have been made include reviewing the characteristics of the

soil, slope improvements, re-slope design, and many more. One way to identify problems is analyzed in terms of the factor of safety of the slope has the potential to fail.

To identify these problems, analyzing the stability of slopes at KM259.95 the North-South Expressway was carried out using the conventional method (infinite slopes method in sand) and computer software; Geo-Studio 2007 (SLOPE/W).

1.3 Objective

This study will be conducted to established following objective:

- i. To analyzing the factor of safety of slopes (cut slope) using conventional methods and computer software; Geo-Studio 2007 (SLOPE/W).
- ii. To making a comparison of factor of safety from conventional methods and computer Geo-studio 2007 software (SLOPE/W) analysis.
- iii. To determine the coefficient of factor of safety from analysis using conventional methods and computer software, Geo-Studio 2007 (SLOPE/W).

1.4 Scope of study

The scope of this study was to determine the stability of cut slopes at KM259.95 the North-South Expressway using conventional methods (infinite slopes method in sand) and Geo-Studio 2007 software (SLOPE/W). Analysis of data using computer software was use three type of simplified soil profile which analyzed data obtained from the site investigation report. To seek solutions to these problems, the analysis and comparison of the slope made between the conventional method and Geo-Studio 2007 software (SLOPE/W).

CHAPTER 2

LITERATURE REVIEWS

2.1 Introduction

General Director of Lembaga Lebuhraya Malaysia (LLM); Datuk Ir Mohamad Razali Othman has issued a statement that, there are 179 slopes in the North-South Expressway, which was found to be at risk of landslides. The situation has sparked concern in many quarters but with more frequent monitoring was carried out. According to him, the factors that contribute to this problem are increases of agricultural activity around the slope which could affect the stability of the slope (Utusan Malaysia, 17.12.2008). The risk of slope failure resulting from natural conditions is hard to predict, but it can be overcome by constantly monitoring and maintenance. For the reason that comes from human activities, it is important for us to know the stability of the slope prior to any activity carried out in order to avoid untoward incidents occurs.

As we know, scientifically landslides occurring due to soil erosion. Soil erosion can be define as a process of destruction and creation of terrain in other areas due to the action of water flowing from the rain that hit the earth until the formation of the water flowing over the surface of the earth, including the flow of the river. This situation can be seen more clearly, especially on the cut slope that has a high gradient. There are two classifications of erosion that occurs naturally and the effects of human activities. However, change the natural terrain difficult to avoid, but it can be solved with the methods of controlling the slope. While the causes of soil erosion from human activities such as agriculture, logging and mining also cause slope failure may be at the expense of lives and loss of property (Pagar Museh, 2013).

2.2 Type of slope

Analysis of slope stability factor to take into account various factors related to topography, geography and characteristics of the soil on the slopes involved. Any information also depends on the type of slope to be analyzed. In general, there are two types of slope that is classified as an infinite slope and finite slope. Besides that, slope has also been classified into two types, namely natural slopes and man-made slopes (Murthy, 2003).

2.2.1 Infinite slope

For too long slope failure that considered a surface parallel to the surface of the earth as the original slope, infinite slope stability analysis is made according to the balance of forces acting on the slices “abcd” in Figure 2.1. While for the equations to obtain the factor of safety is show as Equation 2.1:

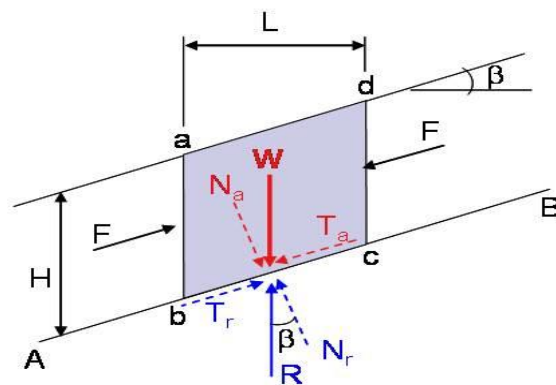


Figure 2.1: Analysis of infinite slope

Source: Winniyarti, 2010

$$\text{FOS} = \frac{c}{\gamma H \cos^2 \beta \tan \beta} + \frac{\tan \phi}{\tan \beta} \quad (\text{Equation } 2.1)$$

where

FOS = factor of safety

c' = effective cohesion of soil (kN/ m²)

γ = unit weight of soil (kN/m³)

W = weight slice (= $\gamma \times$ slices area ($\frac{\text{kN}}{\text{m}}$))

α = inclination of slip surface (degree)

ϕ' = effective friction angle of the soil

β = inclination angle of slope

In the case of ground water level is below the plane of failure (dry slope), and ground friction only ($c' = 0$), the equation as shown in Equation 2.2 can be used to determine the safety factor slope:

$$\text{FOS} = (\tan \phi) / (\tan \beta) \quad (\text{Equation 2.2})$$

2.2.2 Finite slope

When the value of H_{cr} approaches the height of the slopes, the slopes generally may be considered finite. For simplicity, when analyzing the stability of a finite slope is a homogeneous soil, some assumption need to be made about the general shape of the surface of potential failure. Culmann (1875) suggest that slope failure usually occur on curved failure surface. Other than that, after extensive investigation of slope failure in the 1920s, a Swedish geotechnical commission recommended that actual surface sliding may be to be circularly cylindrical. After that assumption has been made, most conventional stability analysis of slopes is considered as arc of a circle as shown in Figure 2.2.

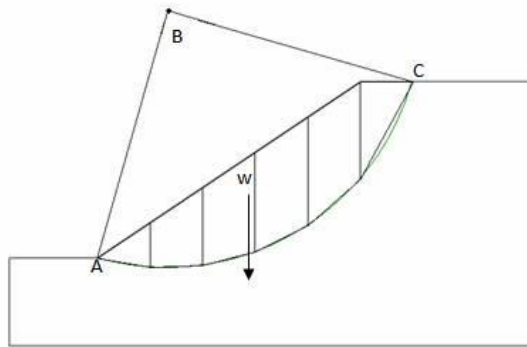


Figure 2.2: Circular slip surface

Source: Indian Institute of Technology

2.2.3 Natural slopes

Natural slopes are usually formed in the hilly areas where the formation processes take a long time without disturbance process. Slope formation is also influenced by the movement of the earth's core and earthquakes. The slopes of this type are also strong and stable as long as no human activities such as logging and mining that disturb the stability of the slope (Shah Jahan bin Abdullah, 2012).

2.2.4 Man-made slopes

Man-made slope is when humans leveling the land for construction, they cut slope or embankment to provide ground level to facilitate construction. This is a man-made slopes and stability should be monitored sari time to time to prevent landslides (Dr. Ibrahim Komoo, 2013). Man-made slopes can be classified into two categories as follows:

- i. Cut slopes
- ii. Fill slopes

2.2.4.1 Cut slopes

Cut slopes categorized as man-made slopes seek to make way for the construction of roads or other infrastructure. This slope construction process involves changing geometry in terms of angle and height. There are guidelines and conditions that must be met in order to build the slope of this kind in Malaysia. All slopes are not treated will be designed with a minimum width of the berm height of 2m and 6m maximum berm with a safety factor greater than 1.3. Stabilization measures may include soil nailing the slope surface protection, permanent soil anchors, retaining walls or any other related methods. Global minimum factor of safety for slope treated was 1.5. (Public Works Department, 2010). Each guideline is intended that the construction is done in the slope of this type are not exposed to the risk of landslides and various other risks such as property damage and casualties.

2.2.4.2 Fill slopes

Fill slope is also one of the man-made slopes with the reclamation of land from other areas. This situation can usually be seen in the area of highway construction. Each slope construction process must adhere to standards set by authorities. All untreated fill slopes should be designed with 2m berm width and 6m berm height with a minimum factor of safety of 1.3. The stabilization measures may include geo-grid or geo-textiles reinforcement, reinforced concrete retaining structure, reinforced fill structure, or replacing the fills with elevated structures. While for the slopes that have been treated, a minimum safety factor of 1.5(Mohd Riza Aizad Bin Shauri, 2012).

2.3 Type of slopes failure

Slope failure can be defined as mass wasting, is the down slope movement of rock debris and soil in response to gravitational stresses. Slope failure can be classified by source and form of the ruins of the movement in the soil. Potential slope failures are usually caused by increased pressure or shear strength of the soil decreases. Usually, a pressure increase will come from increasing the load or vibration element near the slope. Besides that, the increase in pore water pressure can also reduce the shear

strength of the soil and indirectly slope will risk to a landslide. There are several types of failures are identified through the study of causes and forms of ground movement. Types of slope failure are:

- i. Topples
- ii. Flowage
- iii. Sliding
- iv. Lateral spread
- v. Complex

For example slope failure that occurred in our country is on 2004, Malaysia has experienced the latest in a series of landslide when a large rock slope collapse and fail to New Klang Valley Expressway (NKVE) at Bukit Lanjan. The landslides were outstanding, as show in Figure 2.3, closed the highway for several months, prompting a huge cost, though no reports of public who were killed in the incident. (Dave Petley, 7 November 2012).



Figure 2.3: New Klang Valley Expressway (NKVE) landslides at Bukit Lanjan (2004)

Source: American Geophysical Union, 2012

2.3.1 Topple

Topples is the forward rotation out of the slope of mass of soil or rock about a point or axis below the centre of gravity of the displaced mass. Toppling is sometimes driven by gravity exerted by material upslope of the displaced mass and sometimes by water or ice in cracks in the mass (Varnes, 1996). Among the causes of this type of slope failure is of vibration of human activity such as quarrying, cutting slopes that are not in accordance with prescribed standards, excavation, or stream erosion. The Figure 2.4 shows the overview of topple landslide.



Figure 2.4: Topple

Source: Idaho Geological Survey, 2008

2.3.2 Flowage

Flow can be defined as the unconsolidated materials where the material is in the liquid state. Therefore, the water content in the soil is the main mechanism for this process. There are several categories of this type of slope failure as follows:

- i. Debris Flow
- ii. Mudflow

2.3.2.1 Debris flow

A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as slurry that flows down slope. Debris flows are commonly caused by intense surface-water flow, due to heavy precipitation or rapid snowmelt that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material. Fires that denude slopes of vegetation intensify the susceptibility of slopes to debris flows. The overview of this type landslide can be seen in the Figure 2.5.

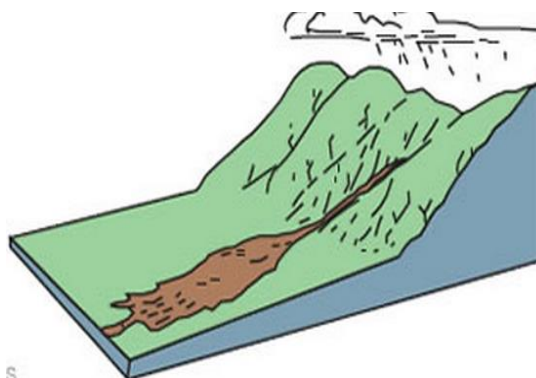


Figure 2.5: Debris flow

Source: Idaho Geological Survey, 2008

2.3.2.2 Mudflow

A mudflow is an earth flow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand, silt, and clay-sized particles. Sometimes, for example in newspaper reports, mudflows and debris flows are commonly referred to as "mudslides". As show in Figure 2.6, mudflow is a kind of slope failures that occur frequently in our country that has a relatively high rainfall.

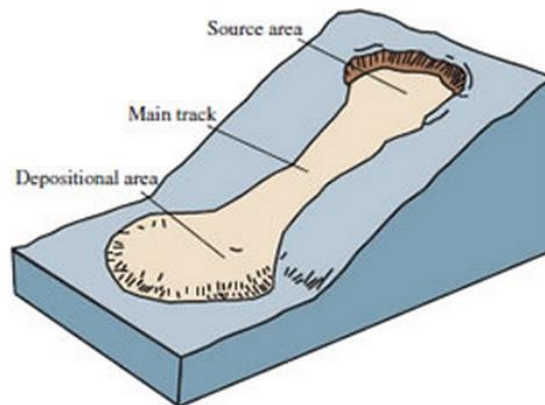


Figure 2.6: Mudflow

Source: Idaho Geological Survey, 2008

2.3.3 Slides

Sliding can be defined as uniform movements in a smooth surface and it is continuous (Dictionary). From the scope of slope failure, it was classified into several types:

- i. Translational slide
- ii. Rotational slide

2.3.3.1 Translational slide

Landslides are mass translational slide downwards and outwards at the top surface of the inclined plane. Slip plane is influenced by stratum stronger base than the upper layer. This difference leads to a lack of adhesion forces between the layers of the structure. Landslides of this type involve a greater failure. This is because the fault plane, which extends for some distance and it is difficult for expected failures. The overview of translational slide is shown in Figure 2.7.

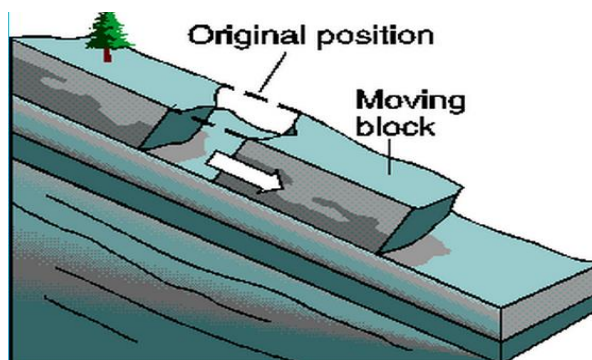


Figure 2.7: Translational slide

Source: Idaho Geological Survey, 2008

2.3.3.2 Rotational slide

Rotational slide or also known as slump, is described is the sliding of a material along a curved surface. The cause for this slide is due to erosion at the base of the slope. The masses technically slide outwards and downwards or more concave-upward failure surfaces that gives a backward tilt to the slipping mass. The failure mass then sinks at the rear and heaves at the toe of the slope. The overview of the rotational flow can be seen in Figure 2.8.

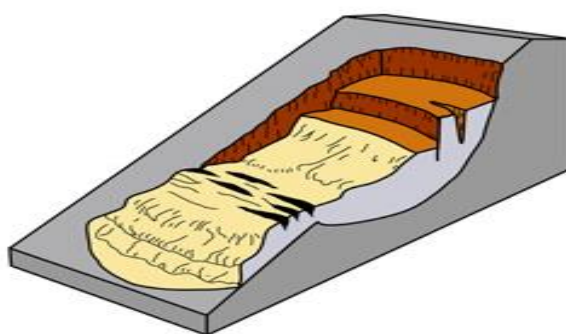


Figure 2.8: Rotational slide

Source: Idaho Geological Survey, 2008

2.3.4 Lateral spread

This type of failure usually occurs at a very gentle slope or wavy. The main mode of movement is lateral extension accompanied by shear or tensile fractures. Failure is usually caused by the rapid movement of soil, such as that experienced during the earthquake. When coherent material, either bedrock or soil, rests on materials that liquefy, the upper units may undergo fracturing and extension and then subside, translate, rotate, disintegrate, or liquefy and flow. Lateral spreading in fine-grained materials on shallow slopes is usually progressive. The failure starts suddenly in a small area and spreads rapidly. Combination of two or more of the above types is known as a complex landslide. (Geology.com, 2005-2014). The overview of the lateral spread can be seen in Figure 2.9.

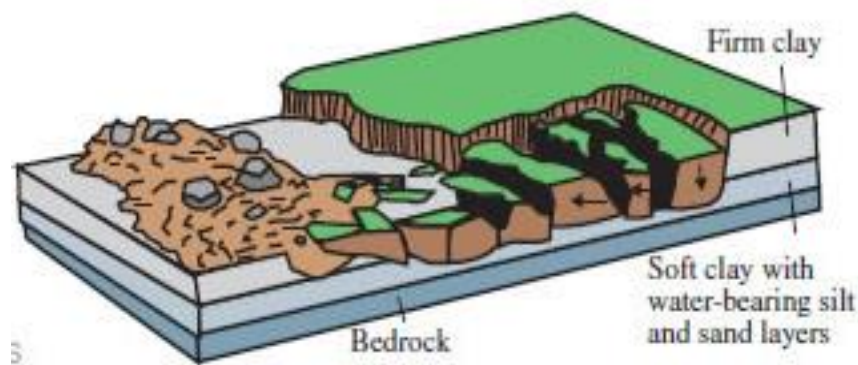


Figure 2.9: Lateral spread

Source: Idaho Geological Survey, 2008

2.4 Factors of slopes failure

Slope stability is an issue that must be emphasized that before any activity carried out mainly in the hilly terrain. This is because there are numerous other major sources can lead to instability of the slope, if underestimated. Among other causes which can lead to slope instability is natural factors and human activities factors. An opinion about the factors affecting landslide in Malaysia is, heavy rain for a long period of time. Second, changes in the material properties of the earth through geomorphologic